Chapter 1
Introduction

Abstract This chapter presents the detailed description of the main timber species applicable in construction industry. Numerous statistical data related to the fire cases in the twenty-first century are discussed (basically in Russia). These data emphasize that the timber and timber products are the main reason for most of the fire cases in timber buildings and structures. The original approach for understanding the fire behavior of timber of different species has been developed: the intensity of fire is a complex function of several interrelated parameters such as chemical structure, physical morphology, technical properties, age of timber constructions, and intensity of external heat flow.

Forests are the primary source of timber. Russia is one of the most forested countries in the world. Almost a quarter of our planet's forests grow on its territory. With a relatively small number of main tree species, we observe great intraspecific variety. The main species usually include those occupying more than 0.1 % of the forested area. They include six coniferous and 13 domestic leaf species (Ugolev 2001). However, a large number of subspecies, varieties, climatic populations, clones, spontaneous crossbreeds, and other biological forms of these main species have been distinguished and described (Ugolev 2001; Kalutskiy 1982).

The formation of rich intraspecific tree polymorphism was facilitated by our country's enormous area; vast forest range; different combinations of soil, hydrologic, and climatic conditions; and many other factors (Shirnin 2004).

It should be borne in mind that the forest ecosystem plays the key role in generating oxygen for the Earth's atmosphere. By also having other environmental (water and climate regulating) functions, it actually determines the condition and survival resources of modern civilization (Kuznetsov and Baranovskiy 2009).

The species composition of Russian forests varies considerably from north to south and from west to east in our country. On the whole, coniferous forests prevail. However, their percentage changes from north to south with consideration of the amount of woodland in different regions. Thus, the percentage of coniferous in the

R. Aseeva et al., *Fire Behavior and Fire Protection in Timber Buildings*,
Springer Series in Wood Science, DOI 10.1007/978-94-007-7460-5_1,

boreal forest is almost 80 %. They occupy about half of the forest stands in the mixed forest area. In the forest-steppe zone, coniferous forests cover a 25 % of woodlands, while in the steppe regions, they occupy only 12 % of forest lands.

Soft deciduous species like birch, aspen, and lime prevail among in the mixed forest area. In the forest-steppe area, mainly hard deciduous species prevail, with oak being predominant (Kalutskiy 1982).

The main forest-forming coniferous in Russia are larch, pine, and fir trees. Larch forests occupy 2/5 of the country's forest land and account for a third of the timber resources. Up to 14 different larch species grow in Russia. Their areas are geographically separated. In the northern limit of the forest ecosystem (subarctic area), Dahurian larch (Gmelin) and Cajander larch are absolutely dominant. It is assumed that during evolution these larch varieties acquired the features allowing them to adapt to extreme frozen ground conditions as well as to fires (Benkova and Benkov 2004).

Tree species such as the Dahurian larch (it occupies 56 % of the area of larch forests), Siberian larch (13.9 %, respectively), and Sukachev larch (total of 0.1 % of woodlands) have the greatest national economic value (Ugolev 2001; Chakhov and Lavrov 2004). Larch-based materials are widely used in civil and industrial construction. Due to their increased decay resistance, they are used in hydrotechnical structures. Like other species, they are also used in the most varied areas of the national economy.

Pine forests rank second among coniferous in abundance, occupying 1/6 of the country's forests, while fir forests rank third (about 1/8 of the area, respectively). Other main coniferous species, in addition to the above-mentioned, include cedar (as well as the Pinus pine), silver fir (Abies genus), and yew (Taxus genus).

Although deciduous forests occupy only 1/5 of our country's forests, they are characterized by greater variety than coniferous ones. Oak (Quercus genus), beech (Fagus genus), ash (Fraxinus genus), lime (Tilia genus), maple (Acer genus), birch (Betula genus), aspen and poplar (Populus genus), elm (Ulmus genus), alder (Alnus genus), walnut (Junglas genus), and others have commercial value for manufacturing various products (Ugolev 2001).

Studies of the variety of morphologic tree species forms in natural forest populations based on the nature of the plants' genetic constitution and genetic conditionality increased rapidly in the second half of the past century. These studies are the scientific basis for the development of applied areas of forestry, have great practical importance for solving problems of breeding timber plants, and for improving timber productivity and quality. The interaction of a certain plant genotype with the growth habitat conditions and the impact of genetic and environmental factors on timber structure, chemistry, and properties (distinctive features) are of special interest here (Rone 1980).

Tree genotypes have individual responses to environmental influence. Tree biometric parameters are most often used as external plant features dependent on hereditary factors. Tree growth parameters are used (in particular, the beginning and end of growth and the ratio of spring and autumn wood in annual rings) to analyze the biological effects of interaction in the genotype–environment system.

Wood strength properties are used as an indication of wood quality. The amount of data on physical and mechanical properties of many tree species from different regions of world countries has increased recently. It is shown that wood's physical and mechanical properties are under strict genetic control. The share of genotype influence on various physical and mechanical properties of timber, e.g., of poplars from the Lower Volga floodplain, reaches 47–77 % (Shirnin 2004).

It is notable that quantitative analysis of purely genetic effects of the development of tree populations considers some biochemical features as well. In particular, data on the number of isoperoxidases in fir needles, as well as on monoterpene content in pine needles, have been successfully used for this purpose (Rone 1980; Baumanis et al. 1978).

Forest woody populations, like other higher green plants, are remarkable living forms having immense biosynthetic capabilities. By consuming water and carbon dioxide, microelements and simple inorganic nutrients providing the plant with only six elements, namely, carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus, they are able to synthesize all of the complex organic substances required to make the components of plant tissues, for tree growth and reproduction. Sunlight is the primary source of energy for biochemical synthesis processes.

At present, extensive data have been accumulated on the anatomical organization and microstructure of various tree species and kinds as well as plant tissue chemistry.

Biochemical genetics of woody plants on the molecular level is the least studied wood science. However, on the basis of available data, the scientific community is already coming to the conclusion today that evolutionary development of woody plants and their natural selection and adaptation are primarily controlled by molecular mechanisms, and only then are determined by ambient conditions. Environmental stresses to a greater or lesser extent affect biosynthesis of the main chemical compounds and so-called metabolites and change the percentage of chemical components in timber.

Timber is a combustible material, like any other organic substance. Timber combustion is primarily a chemical oxidation-reduction process characterized by material degradation, heat liberation, and the formation of various reaction products. But the process of combustion onset, spread, and damping is very complex. It is a combination of both chemical reactions and many purely physical processes (phase transitions, diffusion, heat exchange, mass transfer processes, etc.). For this reason, in order to understand the mechanisms of timber ignition and combustion, and its fire-hazardous characteristics, in addition to knowledge of the chemistry and quantitative content of the main chemical components, one also needs data on the specific features of the timber's texture and its thermophysical and other properties. The nature of thermal impacts on timber-based materials, as well as its operating environment, is very important.

Timber was in fact the first object of an organic polymeric nature used to study the patterns of combustion in solid condensed systems as well as the factors affecting this process. At first, these studies were of a purely empirical nature. They were prompted by the wish to make the most effective use of wood as fuel.

Table 1.1 Effect of fire-resistance rating and building footprint (S, m^2) on the number of fires and human deaths in 2000

Building fire-resistance rating	Building footprint, S, m^2							
	Up to 25		25–100		101–500		More than 500	
	Fires	Deaths	Fires	Deaths	Fires	Deaths	Fires	Deaths
I–II	302	18	97	9	47	2	7	0
III	898	14	448	11	397	6	113	55
IV–V	2,907	67	2,848	60	2,582	95	448	82

Even in the first half of the twentieth century, timber provided most of the total thermal energy consumed in many industrially developed countries (Dunkerely 1980). Timber was attractive because it was a cheap and renewable thermal energy source. At present, timber is a raw material for making many valuable substances and materials, and active efforts are underway to create new technologies for producing gaseous and liquid biofuels from wood. However, the issue of timber's fire safety and the creation of the essential principles of its combustion process and fire protection have come to the forefront.

Global fire statistics shows that fires related to burning forests and timber-based and other organic materials in various kinds of structures pose a real hazard to modern civilization, adding to destabilization of life on our planet (Brushlinskiy et al. 2007). About 6.5–7.5 million fires are registered annually throughout the world, causing the death of 70,000–75,000 people and injuring about one million people. It has been determined that 35 % of all fires occur in buildings, in the majority of cases in residential buildings. Furthermore, the most destructive character of fires with a large number of dead and injured persons, as well as significant material damage, occurs in buildings with timber structures (buildings with fire-resistance rating IV–V). This is obvious from statistical data on fires in Russia for 2000 (Table 1.1) (Data on fires and their consequences for constituent entities of the Russian federation 2000).

Many Russian regions are still characterized by a large area occupied by buildings and structures with fire-resistance rating IV–V (Karelia, Republic of Komi, Arkhangelsk, Vologda, and other regions where timber is a traditional building material).

The observed situation with fires involving timber is not surprising. Chronicles of peoples from various countries include multiple examples of not only huge forest areas destroyed by fires but also of whole cities, which required years of painstaking restoration work. Thus, Moscow's timber buildings were completely burned in 1176. The fires of 1331 and 1337 destroyed the wooden Moscow Kremlin. Even today, forest fires cause enormous damage and destroy the living ecological environment. According to (Fires and fire safety in Russian Federation for 2007–2011 years 2012), as of November 1, 2011, forest fires in the Russian Federation affected millions of hectares of land, destroyed millions of cubic meters of standing forests, and eliminated significant areas of young forests (Table 1.2).

Table 1.2 General data on forest fires in Russia

Years	2007	2008	2009	2010	2011
Number of forest fires	17,812	26,285	23,245	34,812	21,074
Area of lands affected by forest fires, thousand hectares	1,620.3	2,534.8	2,592.6	2,475.3	1,673.8
Burned standing timber, million m^3	16.5	30.1	25.4	93.1	28.7
Dead young forests, thousand hectares	86.2	294.4	119.7	126.6	102.7

Lightning discharges are an important cause of forest fires. However, forest fires are caused to a large extent by human impact (over 60 % of the total number of fires on average). Careless handling of fire is the main cause of 80–90 % of man-induced fires. Factors such as moisture content of timber-based combustible materials, as well as meteorological parameters of atmospheric environment (temperature, humidity, wind speed), have great influence on the character of forest fires. The closeness of populated area and their increased population contribute to an increase in the number of seasonal forest fires. However, a reverse relation is also noted: the impact of forest fires on the occurrence of fires spreading to nearby timber structures of populated areas.

In 2010, forest fires in Moscow Region completely destroyed some villages with timber buildings and structures located close to a forest.

Wood makes up most of the forest ecosystem phytomass. There is a lot in common between the patterns of the onset and spread of combustion during fires in forests and buildings and structures of fire-resistance rating IV–V using timber constructions and building materials. This similarity is due to the organic nature of timber-based combustible materials and constructional timber, which is the main structural component of woody plants.

Consideration of forest fires as a more complex macrosystem, which involves combustion not only of living trees but also of biomass on their tops, undergrowth, and ground cover in the form of tree cutting, fallen needles and leaves, branches, and grass depending on the state of the atmospheric environment, is outside the scope of this book.

Here we confine ourselves only to consideration of the fire safety of most timber products as a material widely used in construction.

It should be noted that partial or full replacement of timber building materials with other inorganic structural materials has increased fire safety of buildings and structures. However, at present they are being increasingly equipped with articles made not only of natural but also of man-made and/or synthetic organic polymeric materials. Therefore, we must agree with the conclusion made by the authors of outline (Brushlinskiy et al. 2007), "that, unfortunately, human life without fires in the foreseeable future is still not guaranteed."

The reason for the majority of fires in buildings and structures according to statistical data for the Russian Federation is careless handling of fire and violation

Table 1.3 Statistical data for fires in RF cities

Main indices	2007	2008	2009	2010	2011
Number of fires, thousand	138.3	130.0	116.5	109.8	103.6
Loss of life, persons	8,643	8,432	7,363	6,809	6,129
Injured persons	9,608	8,887	9,151	8,965	8,565
Direct material damage, billion roubles	5.172	8.221	7.252	7.101	12.660

Table 1.4 Statistical data for fires in RF rural areas

Main indices	2007	2008	2009	2010	2011
Number of fires, thousand	74.3	72.0	71.0	69.8	65.0
Loss of life, persons	7,423	6,869	6,583	6,261	5,889
Injured persons	4,080	4,000	4,118	4,182	3,951
Direct material damage, billion roubles	3.524	4.007	3.941	7.454	5.382

of electrical equipment installation and operation rules. Thus, in 2005, nearly every second fire was caused by careless handling of fire and every fifth one by violation of electrical equipment operation rules. In 80 % of cases, loss of life in fires is caused by poisoning by toxic combustion products.

Tables 1.3 and 1.4 give the main statistical data for fires in RF cities and rural areas from 2007 to November 2011 (Fires and fire safety in Russian Federation for 2007–2011 years 2012).

A comparison of statistical data shows that the number of fires in cities is about twice as high as in rural areas. However, a higher number of victims in relation to the number of fires is characteristic of rural areas. This is related to the wide use of timber and timber-based materials in rural areas for constructing various buildings and structures.

The wide use of timber as a structural building material and its higher combustibility promoting the development and spread of fires are prompting focused efforts to protect timber structures and materials against fire and high temperatures. A successful solution to the issue of fire safety and finding the most reasonable and efficient measures for protecting timber against fire are impossible without knowledge of the fundamental scientific basis of timber combustion and factors affecting the mechanisms of this process.

The phenomenological pattern and physical and chemical basis of the wood combustion process are shown in the following diagram (Fig. 1.1).

A combustible material is heated when it is subjected to an external heat flow (radiant, convective, or combination thereof). If heat flow is relatively high, the material's surface temperature reaches the level at which its pyrolysis begins. Timber pyrolysis is the unreversible reaction of thermal decomposition of material forming volatile and nonvolatile products in the condensed state. The gases or vapors of combustible products that are formed are mixed with air in the layer boundary. Under certain conditions, this mixture exceeds the lower flammability limit of combustible substances and ignites. The timber ignition process may be spontaneous or initiated by a small ignition source localized in the boundary layer.

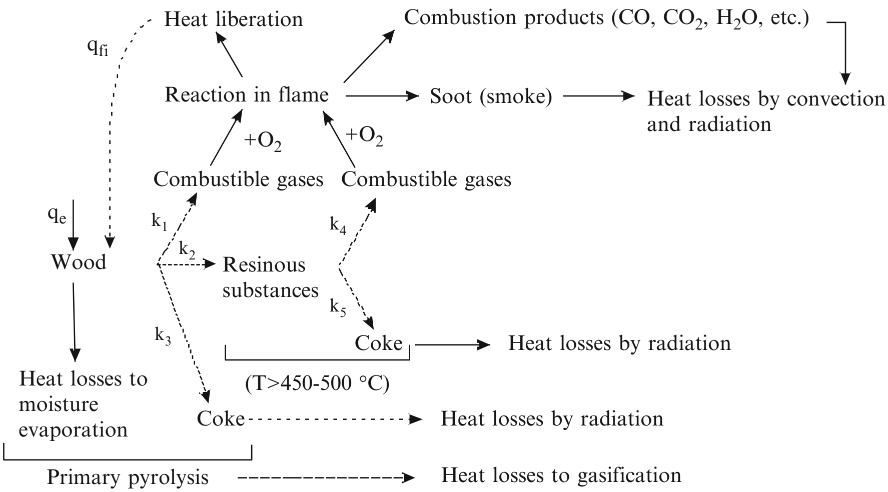

Fig. 1.1 Diagram of the chemical and physical processes during flame combustion of timber

This source may be a small flame of a gas burner, electric spark, or red-hot wire. In scientific literature, this process of ignition of flammable condensed systems is called piloted ignition. After ignition, heat flow to the timber surface is a combination of the external flow and reverse heat flow from the initiated flame.

Chemical and physical processes during combustion of polymeric materials occurring in the gas phase (ignition, flame spread, extinguishing, exothermal reactions in flame, etc.) determine many of the fire safety characteristics of materials.

Heating and decomposition of organic material are important stages of the timber combustion process. The speed of heating to the decomposition temperature depends not only on the intensity of the external heat source but also on the timber's thermophysical properties, which are closely related to its structure. Timber decomposition rate under the given heating conditions is to a large extent determined by the chemistry of this natural composite.

Timber is a striking representative of polymeric carbonaceous materials (Aseeva and Zaikov 1981). As the pyrolysis front moves inside the material, a char layer forms and grows on its surface. This reduces the amount of combustible volatile products, since a portion of the carbon and hydrogen (the main combustible elements in the chemical composition of timber) remains in the condensed phase. The char layer with low thermal conductivity acts as heat insulation, reducing the heat flow to the underlayers of the original wood. At the same time, it may act as a physical barrier hindering the escape of decomposition products to the gaseous phase or oxygen access to the timber surface. In addition to these effects, the temperature increase on the char layer surface during combustion development causes increased heat loss due to radiation from the char surface. The above-mentioned factors taken together have a great impact on the mechanisms of the timber combustion process.

We should expect that variations in timber chemistry and structural properties depending on the species and variety will affect the direction of chemical reactions, the macrokinetic features of timber pyrolysis and carbonization, and the amount (thickness), structure, and properties of the char that is formed. All other conditions being equal, it should affect the speed of burnout, ignition, and flame spread along the timber surface, the formation of smoke, and toxic combustion products, and in the long run, the main fire safety indices for timber-based materials. This is the reason for the recent interest in comparative studies of pyrolysis and thermo-oxidative decomposition of various timber species and the separate chemical components of wood in a wide temperature range. The speed and degree of timber pyrolysis determine the speed of timber burnout, carbonization and integrity, as well as the mechanical strength of timber structures during fires.

The detailed mechanism and kinetics of chemical reactions of wood pyrolysis and carbonization have still not been conclusively established. Earlier works in this area focused almost exclusively on materials based on cellulose or its derivatives (Shafizadeh 1984; Roberts 1970).

Until the 1970s, there were heated discussions about whether the results of pyrolysis kinetic studies conducted on small samples of substances and materials by thermal analysis methods (TG, DTG, DTA, DSC) under isothermal or dynamic heating conditions could be used for modeling pyrolysis and burnout of large bulk samples. This was because pyrolysis first of all has a volumetric character and occurs in the entire volume of a sample heated to a certain temperature. Second, it starts on the surface and moves inside the sample and has properties of linear pyrolysis. Higher temperatures and large temperature gradients are observed near the material surface. The decomposition process, in fact, takes place in a narrow area, the width of which depends on the thermal and physical characteristics of the polymeric material and heating conditions. Detailed studies have shown that pyrolysis occurs throughout the volume of this narrow reaction zone. The effective macrokinetic parameters of pyrolysis of many polymeric materials, including wood, obtained from data of thermogravimetric measurements at lower heating rates and temperatures than during combustion, are quite in keeping with the parameters of linear pyrolysis of large samples (Aseeva and Zaikov 1981; Roberts 1970).

Modern instrumental equipment and computer software for thermal analysis make it possible to study pyrolysis of substances on very small samples (weighing 1 mg or less). It prevents the dynamics of pyrolytic reactions from being affected by adverse diffusion effects and nonuniform temperature distribution in the sample, and allows the macrokinetic parameters at certain stages of the substance decomposition process, as well as thermal effects of reactions in a wide temperature range, to be determined with high accuracy and reliability. Moreover, the procedure developed for processing experimental thermal analysis results allows an assessment of the type of mechanism of solid-phase reactions of substance decomposition (Shestak 1987; Rogers and Ohlemiller 1981).

Timber pyrolysis under the impact of high-temperature heat flows causes the formation of various products that enter the gaseous phase and support the flaming process. Several main spatial areas differing in their temperature characteristics,

type, and speed of chemical reactions can be distinguished in the diffusion flame during timber combustion, the same as in the condensed phase. The gas-vapor flame portion adjacent to the surface is considered the pre-flame area, visually observed in the form of a dark region in the lower flame portion. It is sometimes called the cold flame zone. The active exothermal reaction of oxidation of combustible volatile products of wood substance decomposition occurs in a narrow area of the flame front. Very high temperatures and a higher temperature gradient are observed here in the bright reaction layer on the flame surface. It is thought that oxygen diffusing from the ambient air to the flame reacts with gaseous fuel in the flame front in a stoichiometric ratio. Finally, the intensely luminous area inside the flame is an area of combustion products from which condensed particles are emitted as smoke through the flame peak.

There are no experimental data on stable compounds and active particles that should be characteristic of different areas of a timber diffusion flame. This is due not only by issues related to flame probing and analysis and the labor intensity of these procedures but also to the complexity of the multicomponent carbonaceous system being analyzed. It is known that carbonization affects flame structure stability (Aseeva and Zaikov 1981).

Timber pyrolysis during heating without air access up to 500 °C is well known in wood science as the dry distillation process for obtaining many valuable substances (Fengel and Vegener 1988).

Beginning in the twelfth century, this was one of the first processes of the chemical technology of organic substance production widely used in Russia to make resin, and later charcoal.

Modern analysis methods have revealed that products of timber pyrolysis in an inert medium contain more than a hundred compounds belonging to different chemical classes (Fengel and Vegener 1988). They vary in volatility at the temperature reached on a timber surface during an external thermal action. Ignition and combustion of each compound have their own features and patterns. The situation becomes even more complicated when mixtures of these compounds react. Various chemical reactions involving gaseous compound transformation occur in each flame zone. Polymeric materials less complex than wood were used to obtain experimental evidence that active processes related to cracking of organic compounds. That is, volatile products of polymer pyrolysis already occur in the pre-flame area (Aseeva and Zaikov 1981). The formation of smoke aerosol during timber combustion is an evidence of incomplete oxidation of pyrolysis products in the flame.

Mathematical modeling of these processes, followed by comparing the numerical results obtained with the experimental data, is an important tool for analyzing various factors affecting timber ignition and combustion.

The first attempts at a theoretical study of gas-phase ignition of solid fuels under the impact of external heat flow were based on thermal models focusing on chemical processes in the gaseous phase. The ignition criterion was a fast exothermal chemical reaction in the gaseous phase (Aseeva and Zaikov 1981; Kashiwagi 1974). The main problem with practical use of these models is related to the need to know many important characteristics of processes occurring in the

gaseous phase. However, it is very difficult to determine these parameters as the specific reaction rates of gaseous compounds or their mass transfer coefficients at high temperatures.

Some researchers suggested an alternative, less complex approach to modeling wood ignition and combustion. This approach is based on the use of indirect ignition criteria reflecting the required inflow of combustible products into the gaseous phase due to solid fuel pyrolysis. Until then, it was considered an inert material (Aseeva and Zaikov 1981; Janssens 1991).

In turn, modeling of the process of flame spread along the surface of solid materials is based on the concept of continuous gas-phase ignition of material decomposition products. In this case, the initiated flame acts not only as a source of material heating and pyrolysis but also as a piloted source of ignition of the volatile flammable compounds produced. Considering the features of pyrolysis of carbonaceous materials, such as timber, allows an assessment of the critical conditions for flame spread along the surface of these materials.

Mathematical models of varying complexity were developed to describe timber pyrolysis and carbonization, and burnout in flaming and smoldering modes. These topics will be considered in greater detail in subsequent chapters of the book.

Analysis of the results of experimental and theoretical research on timber pyrolysis, ignition, and combustion makes it possible to distinguish a number of factors as the key variables affecting the fire safety of timber-based materials. Some of them depend on the timber variety and thus on its chemistry and structure (e.g., density, thermophysical, and thermochemical properties). Other factors are determined by the conditions under which the above-mentioned processes can take place (intensity and type of external thermal effect, environmental properties, sample orientation and size).

Timber remains one of the most attractive materials for the construction industry. It is used as load-bearing and enclosing structures of buildings, finishing, and facing materials. The development of modern house-building was largely facilitated by the creation of advanced industrial processes for manufacturing new structural materials from timber. In the first place, there is glued laminated timber (glulam), CLT (cross-laminated timber) panels, slabs, LVL (laminated veneer lumber) beams, and OSB (oriented strand boards) made of large wood particles. The specific geometry and orientation of wood particles in the OSB board structure increase the strength of this material and expand the opportunities for using it in building structures.

In the USA, Canada, and Europe, the low- and medium-rise frame timber house-building sector is developing very rapidly. The appropriate space planning and engineering solutions have been developed using passive and active fire protection means to ensure fire safety in timber buildings.

Modern timber house-building technologies are implemented less actively in Russia than in European countries. Thus, the relative volume of timber used in domestic house-building is 20 times less than in Finland or Sweden (Kobeleva 2012). To a large extent, this is due to insufficient development of domestic fire protection standards for timber house-building as well as the absence of a unified system program for building timber houses and structures in the Russian Federation.

In spite of the existing materials science, technological and regulatory barriers, real estate market experts anticipate that Russia will have an average annual growth rate in demand for timber buildings of 10 % until 2015 and 20–25 % by 2020 (Kobeleva 2012).

At present, glued load-bearing timber structures (columns, beams, arcs, frames) are being used to construct several unique large span structures. It suffices to name the sports complex in Arkhangelsk with a span of 63 m, an indoor ice rink in Tver with a span of 58 m, a mineral fertilizer warehouse in the port of St. Petersburg with a span of 63 m, and arc comb height of 45 m (Aseeva et al. 2010). Designs for public timber frame buildings and structures more than 9 m high have been developed, which, however, require specific engineering solutions for fire protection of timber structures and fire safety of facilities (Architectural and educational resource).

The stability of buildings and structures in case of fire depends on the fire-resistance rating of its load-bearing constructions. It is known that timber constructions lose their bearing capacity due to timber charring and the resistance of the material and joint connections to mechanical and thermal loads is significantly reduced. The fire-resistance rating of load-bearing constructions is determined according to the time of reaching the limit state according to a specified feature (R) when the structures are tested in standard temperature conditions of fire. It is very important to know the speed of timber charring, how its mechanical properties change during fire, and to what extent the given characteristics depend on the nature and variety of the timber, its humidity, a change in fire conditions, and construction heating.

Unlike load-bearing structures, the functions of enclosures and enclosing parts of buildings and structures amount to preventing fire from spreading to rooms adjacent to the fire seat and limiting the impact of hazardous fire factors on humans (smoke, toxic products, temperature increase, etc.). Therefore, fire resistance of an enclosure is assessed according to time (a) of structure integrity damage with the formation of cracks and through holes through which combustion products and flame penetrate (feature E), (b) of loss of thermal insulating capacity and a critical increase in the construction's surface temperature on the other side not exposed to fire (feature I), and (c) of reaching the permissible heat flux density (3.5 kW/m$^2 \pm 5$ %) at a standardized distance (0.5 m) from the structure's unheated surface (feature W).

Criterion I is fulfilled if the average temperature on the unheated surface of the entire timber structure does not exceed 140 °C, while the maximum temperature rise at any point on the surface does not exceed 180 °C.

Various methods have been suggested to protect timber structures against fire, including both structural fire protection and surface treatment with flame retardants. New effective fire protection means for timber structures that retain the natural material's appearance, beauty, and texture under normal operating conditions are of great interest. This is particularly important with respect to preserving and protecting ancient architectural monuments. However, the question of the influence of timber variety and its structural features on the effectiveness of fire-protection treatment remains open.

Timber structures are a priori considered less durable than stone, brick, or reinforced concrete ones. However, the unique timber architectural monuments surviving to our time show that timber as a structural material has relatively high durability (over 300 years). Remnants of ancient archaeological timber several thousand years old have been found (Fengel and Vegener 1988).

Material durability usually means its duration of service under various conditions without significant loss of performance. Under natural conditions of timber members operation, complex interrelated physical and chemical processes of timber aging occur under the impact of light, heat, moisture, wind, biological destroyers, and other factors. Destructive reactions change the structure and chemistry of timber and many of its properties. Scientific literature has not given due consideration to the impact of natural and artificial wood aging on the change on fire safety and fire resistance of timber structures.

We have adopted a concept according to which wood is considered as a natural composite carbonaceous material. Its behavior during fire, as well as the fire safety and fire resistance of timber structures, should simultaneously depend both on the physical (morphological) structure and the material chemical composition, including the chemical nature of the components in this composite and thermal action conditions. This approach provides an understanding of the behavior of different kinds of timber in case of fire, impact of the duration of aging on the change in fire safety characteristics, charring speed, and properties of the char layer forming on a timber surface.

This is why we believed that first of all, it was necessary to briefly present the known data on the structural features, chemistry, and some properties of timber. It also seemed reasonable to consider biogenetic and biochemical aspects of timber polymorphism. This information helps us to understand the difference in the behavior of timber-based materials in their reaction to fire and high-temperature effects as well as how great or small the differences in fire safety characteristics of various species and kinds of timber may be.

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